

GaInNAs-Base NpN DHBTs Grown by GS-MBE with 2% Nitrogen Composition

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GaAs-based heterojunction bipolar transistors (HBTs) have achieved widespread use in high performance microwave and digital applications. However, they have a large base-emitter turn-on voltage V_{BE} of approximately 1.4 V (at high current density). It is important to develop techniques to reduce the value of V_{BE} , particularly for low power applications.

In this work, GaInNAs is used in the base of a GaAs HBT to reduce the turn-on voltage of the transistor. The incorporation of small amounts of nitrogen into GaInAs reduces the net strain of the material grown on GaAs, which is the limiting factor for HBTs with GaInAs bases. The added nitrogen also significantly reduces the bandgap energy, with the majority of difference taking place in the conduction band. To overcome the large conduction band discontinuity between GaAs and GaInNAs both chirped compositional grading and delta doping were employed. Previous work on GaInNAs-based HBTs has achieved a 0.2 V reduction in turn-on voltage V_{BE} with an abrupt GaInP emitter material grown by metal-organic vapor phase epitaxy [1]. We have previously reported large area GaInNAs-base HBT with a 0.4 V reduction in turn-on voltage ($N \sim 2\%$) [2]. In this paper, we report our first small area GaInNAs-base HBT results grown by GS-MBE, with a 0.4 V reduction in turn-on voltage relative to a GaAs-base HBT, shown in Fig. 1.

To further characterize GaInNAs-base HBTs, small area devices were processed with emitter finger area of $3\mu\text{m} \times 3\mu\text{m}$ by 2. GS-MBE was used to grow the HBTs with thermally cracked arsine as the arsenic source and RF nitrogen plasma provides the active nitrogen species. This presents a challenge to obtain high base doping, due to hydrogen passivation of the base layer. Large area devices suffered from large knee ($V_K = 1.3$ V) and offset voltages ($V_{CE,sat} = 0.6$ V) as well as base width modulation. The reduced parasitic resistance of the extrinsic base in the small area device yields a smaller $V_K=0.5$ and $V_{CE,sat} = 0.1$ V, as shown in Fig. 2. These devices have a peak incremental current gain of 8. Fig. 3 shows the frequency response for the GaInNAs-Base DHBTs. At a collector current density of $J_C=2.6 \times 10^4$ A/cm² a cutoff frequency f_T of 23 GHz and maximum frequency of oscillation f_{max} of 10 GHz is achieved. The base sheet resistance from TLM measurements was found to be $\rho_s \sim 7\Omega/\square$ ($W_B=40\text{nm}$) which limits f_{max} .

In conclusion, we have characterized small area GaInNAs based HBTs that have a decrease in turn-on voltage of 0.4 V relative to an HBT with a GaAs base. The large base resistance has degraded output conductance and f_{max} . In order to make these devices competitive with other GaAs based HBT technologies it is important to further optimize the growth of the base layer to achieve higher p type free carrier concentration. Besides improving the growth conditions, improved device design can also increase the performance of these

transistors. Further scaling of the emitter finger width and BE spacing can improve f_{max} and compositionally grading the base can improve f_T . Further characterization needs to be done to determine the effect N has on the minority carrier transport through the base. This technology may be promising for low power or low supply voltage applications.

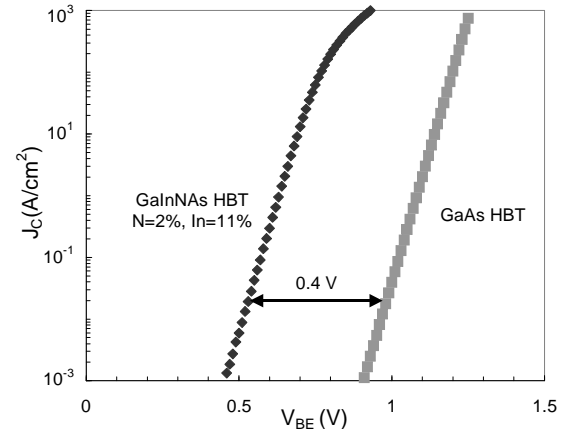


Fig. 1: Comparison of turn-on voltage for GaInNAs vs. GaAs base HBTs. Both have graded BE junctions.

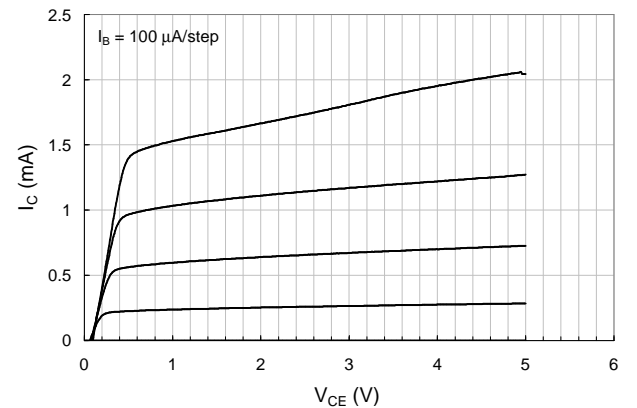


Fig. 2 Common emitter IV curves. Output conductance is due to base width modulation).

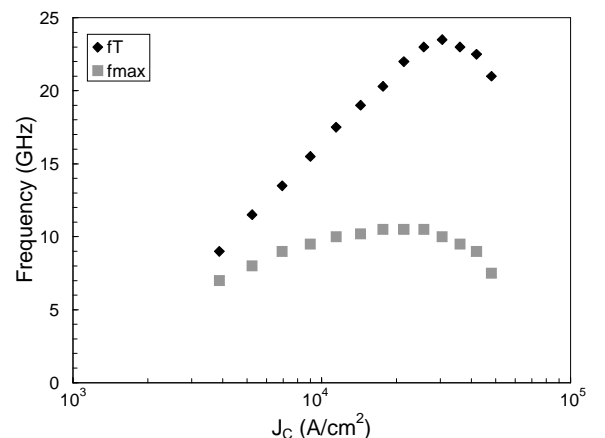


Fig. 3 Collector current vs. frequency with $V_{CE} = 1.5$ V.

- [1] N.Y. Li, P.C Chang, A.G. Baca, X.M. Xie, P.R. Sharps and H.Q. Hou, *Electronics Letters*, vol. 36, no. 1, pp. 81-3, 2000.
- [2] R.J. Welty, H.P. Xin, K. Mochizuki, C.W. Tu and P.M. Asbeck, *Proceeding of DRC Digest*, pp. 145-146, 2000.